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APPARATUS AND METHOD FOR GRAVEL PACKING AN INTERVAL OF A WELLBORE

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APPARATUS AND METHOD FOR GRAVEL PACKING AN INTERVAL OF A WELLBORE

CROSS-REFERENCE TO RELATED PATENT APPLICATIONS

[0001] None

TECHNICAL FIELD OF THE INVENTION

[0002] This invention relates in general to preventing the production of particulate materials through a wellbore traversing an unconsolidated or loosely consolidated subterranean formation and, in particular to, an apparatus and method for obtaining a substantially complete gravel pack within an interval of the wellbore.

BACKGROUND OF THE INVENTION

[0003] Without limiting the scope of the present invention, its background is described with reference to the production of hydrocarbons through a wellbore traversing an unconsolidated or loosely consolidated formation, as an example.

[0004] It is well known in the subterranean well drilling and completion art that particulate materials such as sand may be produced during the production of

hydrocarbons from a well traversing an unconsolidated or loosely consolidated subterranean formation. Numerous problems may occur as a result of the production of such particulate. For example, the particulate causes abrasive wear to components within the well, such as tubing, pumps and valves. In addition, the particulate may partially or fully clog the well creating the need for an expensive workover. Also, if the particulate matter is produced to the surface, it must be removed from the hydrocarbon fluids by processing equipment at the surface.

[0005] One method for preventing the production of such particulate material to the surface is gravel packing the well adjacent the unconsolidated or loosely consolidated production interval. In a typical gravel pack completion, a sand control screen is lowered into the wellbore on a work string to a position proximate the desired production interval. A fluid slurry including a liquid carrier and a particulate material often referred to in the art as "gravel" or "sand" is then pumped down the work string and into the well annulus formed between the sand control screen and the perforated well casing or open hole production zone.

[0006] The liquid carrier either flows into the formation or returns to the surface by flowing through the sand control screen or both. In either case, the gravel is deposited around the sand control screen to form a gravel pack, which is highly permeable to the flow of hydrocarbon fluids but restricts the flow of the particulate carried in the hydrocarbon fluids. As such, gravel packs can

successfully reduce or eliminate the problems associated with the production of particulate materials from the formation.

[0007] It has been found, however, that a complete gravel pack of the desired production interval is difficult to achieve, particularly in long or inclined/horizontal production intervals. These incomplete packs are commonly a result of the liquid carrier entering a permeable portion of the production interval causing the gravel to form a sand bridge in the annulus. Thereafter, the sand bridge prevents the slurry from flowing to the remainder of the annulus that, in turn, prevents the placement of sufficient gravel in the remainder of the annulus.

[0008] Prior art devices and methods have been developed which attempt to overcome this sand bridge problem. For example, attempts have been made to use devices having perforated shunt tubes or bypass conduits that extend along the length of the sand control screen to provide an alternate path for the fluid slurry around the sand bridge. It has been found, however, that shunt tubes installed on the exterior of sand control screens are susceptible to damage during installation and may fail during a gravel pack operation. In addition, it has been found that it is difficult, time consuming, and expensive to make all of the necessary fluid connections between the numerous joints of shunt tubes required for typical production intervals.

[0009] Another approach has been to provide a shroud in the annulus between a sand control screen and a borehole. A shroud is a generally cylindrical member with ports allowing fluid flow between the inside and outside

of the cylinder. The shroud divides the annulus into a medial annulus between the screen and the shroud and an outer annulus between the shroud and the borehole. The fluid slurry is then pumped into one or both of the medial annulus and the outer annulus. If a sand bridge forms in the outer annulus, the slots or perforations in the shroud allow the slurry to bypass the sand bridge by flowing into and back out of the medial annulus. Likewise, if a sand bridge forms in the medial annulus, the slots or perforations in the shroud allow the slurry to bypass the sand bridge by flowing into and back out of the outer annulus. After formation of a sand pack, the shroud remains in place during production. The shroud is therefore provided with a sufficient number of ports to allow free flow of produced fluids. The high permeability of the shroud desired for production has been found to cause problems during the sand packing operation. For example, if a sand bridge forms due to a high permeability zone, the slurry fluid may continue to leak off into the zone during the rest of the sand packing operation. Slurry pumped past the leak off zone therefore has a higher concentration of particulates, requiring higher pumping pressure which increases the chance of formation of another sand bridge and increasing the leak off rate.

[0010] Therefore there could be advantages for an apparatus and method for gravel packing a production interval traversed by a wellbore that overcomes the problems created by sand bridges, leak off zones, etc. There also could be advantages for such an apparatus that is less susceptible to damage during

installation or failure during use. Further, there could be advantages to such an apparatus that is not difficult or time consuming to assemble.

SUMMARY OF THE INVENTION

[0011] The present invention disclosed herein comprises an apparatus and method for gravel packing a production interval of a wellbore.

[0012] The apparatus for gravel packing an interval of a wellbore of the present invention comprises a shroud adapted to be placed in a borehole around a sand control screen to facilitate formation of a sand pack between the screen and a borehole wall and adapted to remain in place during production of fluids from the well. The shroud defines a medial annulus between the screen and the shroud and an outer annulus between the shroud and the borehole. The shroud includes a relatively small number of packing ports and a relatively large number of production ports. The production ports are sized and positioned to provide a relatively unrestricted flow of produced fluids. However, the production ports are substantially closed or plugged with a removable material during formation of a sand pack to at least substantially prevent flow of fluids from the medial annulus to the outer annulus through the production ports. The packing ports are sized, shaped and positioned to facilitate distribution of slurry throughout the producing interval despite possible formation of sand bridges and to limit fluid loss from the slurry to high permeability zones.

[0013] In one embodiment, the packing ports are a preselected set of the production ports which have been partially blocked with removable material to provide a preselected flow area corresponding to a desired packing port size.

[0014] In one embodiment, the production ports are partially or completely closed during the packing operation by a material which degrades as a result of contact with ambient materials in the borehole or with chemicals that may be pumped into the producing interval after formation of a sand pack.

[0015] In another embodiment, the production ports are partially or completely closed during the packing operation by a material that may be removed from the production ports by pressure, vibration or other mechanical means.

[0016] In some embodiments, the removable materials are formed into plugs that may be mechanically engaged with production ports to at least partially block the production ports or to produce temporary packing ports. The plugs of removable material may be formed inside a metal sleeve adapted to mechanically engage the production ports. When the material is removed from the sleeves, fluids may flow through the sleeves, which then define the production ports. The plugs, with or without sleeves, may have threads on their outer surface adapted to thread into threads on the inner surface of the production ports. Alternatively, the plugs, with or without sleeves, may be sized and shaped to form an interference fit into the production ports, or may include a lip on one or both ends, or other engaging shape, which allows the plugs to be

forced into the production ports and to be anchored in place until such time as they are removed for the production process.

[0017] In another embodiment, the production ports are closed during the packing operation by one-way or check valves that allow fluids to flow from the outer annulus into the medial annulus, but do not allow flow in the opposite direction.

[0018] In one embodiment, some of the plugs blocking flow though the production ports have a relatively small opening through which fluids may flow to aid in dewatering of the slurry during the packing process. The small opening may be through the removable material.

BRIEF DESCRIPTION OF THE DRAWINGS

[0019] For a more complete understanding of the features and advantages of the present invention, reference is now made to the detailed description of the invention along with the accompanying figures in which corresponding numerals in the different figures refer to corresponding parts and in which:

[0020] Fig. 1 is a cross sectional view of an embodiment of the invention positioned in a producing interval of a borehole in preparation for placing a gravel pack;

[0021] Figs. 2A, 2B, 2C, 2D and 2E are partial cross sectional views of various embodiments of plugs useful for blocking flow through production ports in a packing shroud shown in Fig. 1;

[0022] Fig. 3A, 3B, 3C and 3D are cross sectional views of a side wall of a shroud according to an embodiment in which various embodiments of flow restricting tubes are positioned in packing ports; and,

[0023] Fig. 4 is a cross sectional view of an embodiment of a shroud in which production ports are blocked by a removable sleeve carried on the inner surface of the shroud.

DETAILED DESCRIPTION OF THE INVENTION

[0024] While the making and using of various embodiments of the present invention are discussed in detail below, it should be appreciated that the present invention provides many applicable inventive concepts that can be embodied in a wide variety of specific contexts. The specific embodiments discussed herein are merely illustrative of specific ways to make and use the invention, and do not delimit the scope of the present invention. As one example, while one typical embodiment of this disclosure involves gravel packing an open hole interval with a borehole wall comprising loose or unconsolidated material, the disclosed apparatus and approaches could also be beneficial in a cased hole where the borehole wall comprises a cemented casing on top of the formation.

[0025] A shroud useful in various embodiments of the invention generally comprises any hollow substantially cylindrical member having several characteristics. It has sufficient strength to be positioned in a wellbore in which a sand pack is to be formed. It may be attached to a sand screen device and carried with the screen when it is placed into the borehole. The shroud could be

placed into the borehole separately and the screen could be then placed inside the shroud. A shroud has sufficient permeability between its inner and outer surfaces to allow produced fluids to flow to a sand screen during production of a well. The permeability may be formed by a plurality of openings, which may be round, square, rectangular, or otherwise shaped and are herein referred to as ports. The openings are generally large enough to allow packing slurry, i.e. both carrier fluid and aggregate, to flow through the shroud. In an alternative embodiment, the shroud may be formed of a screen type material, with a plurality of larger perforations formed through the screen to allow flow of slurry.

[0026] With reference to figure 1, an embodiment of the invention will be described. A borehole 10 extends from a surface location, not shown, to a bottom hole location 12. An upper portion 14 includes a casing 16 sealed to the borehole 10 by cement 18. A lower portion 20 of the well 10 is uncased in this embodiment, although the invention may also be used in cased portions of wells. In this example, the uncased portion 20 is assumed to be in a productive earth formation from which it is desired to produce, oil, gas or other fluids. A sand screen 22 has been positioned within the uncased portion 20 by a work string 24, through which a packing slurry may be pumped downhole as indicated by the arrow 26. A conventional cross over device 28 connects the work string 24 and the sand screen 22. The cross over 28 delivers packing slurry 26 to an annulus outside screen 22 and allows the carrier fluid portion of the packing slurry to be produced back up the well annulus 44 as indicated by the arrow 30, in a

conventional manner. A wash pipe 32 extends from the cross over 28 down through the interior of the sand screen 22 to the lower end of the screen 22.

[0027] The sand screen 22 may be any conventional sand screen. For example, it may comprise a hollow cylindrical base pipe or mandrel having a plurality of ports and a wire screen wrap which allows flow of fluids, but blocks flow of particulates such as sand. The filter material may alternatively be a sintered metal or other filter media suitable for use in oil wells. The particular form of sand screen is not essential to the present invention. In similar manner, the wash pipe 32 may be a conventional tubular member.

[0028] A shroud 34 is also carried on the lower end of work string 24 and extends down over the outside of the screen 22 to the lower end of the screen 22. The shroud 34 may be sized to form a close fit to the inner surface of casing 16. It may carry one or more cup seals 36 to form a closer fit, or to substantially seal, to the casing 16 if desired. In the illustrated embodiment, the cross over 28 has at least one outlet 38 that provides for a flow of packing slurry to a medial annulus formed between the shroud 34 and the sand screen 22. In some embodiments, a second outlet 40 may be provided to also allow slurry to flow to an outer annulus between the shroud 34 and the borehole 10. A packer 42 is provided between cross over 28 and the casing 16 to prevent the slurry from flowing up the annulus 44 between the work string 24 and the casing 16.

[0029] In some cases, the available equipment, including cross over tool 28, will result in the cross over 28 being positioned a considerable distance, e.g. one

hundred feet or more, up hole from the location of screen 22 and shroud 34. In such cases, the outlets 38, 40 will flow slurry into the annulus 44 below packer 42. Until the slurry reaches the top of shroud 34, there is no medial annulus and outer annulus. A close fit of the shroud 34 to the casing 16 and/or the cup seals 36 may be used to force all or most of the slurry flow into the medial annulus if desired.

[0030] As used herein, the term annulus means the space between two generally cylindrical members, whether or not the cylindrical members are centered within each other. For example, the space between shroud 34 and the borehole 10 may have substantially different width at various points, particularly in a horizontal borehole in which the shroud tends to lay directly on the lower side of the well. Centralizers may be used with the tubing 24, screen 22 and shroud 34 as is well known in the art of well drilling and completion. Even with centralizers, the various elements may be eccentrically positioned. In some cases, eccentric spacing may be desirable as discussed below.

[0031] As with prior art shrouds used for gravel packing, the shroud 34 includes a large number of ports or perforations 46 distributed over its length. In this embodiment however, a majority of the ports 46 are reserved for production use and are entirely or substantially plugged or blocked during the sand packing operation as indicated at 48. Ports 48 are referred to as production ports for the purposes of this disclosure. Only a small number of the ports 46 are used for the packing process and are given the reference number 50 and are referred to as

packing ports. The drawing indicates that the production ports 48 are blocked and the packing ports 50 are open when the shroud is placed into the borehole 10 in preparation for forming a gravel pack. The production ports are closed by a material that is removable as described in more detail below.

[0032] In operation of embodiments of the present invention, the assembly shown in Fig. 1 is placed in a well interval in which a sand pack is desired. A packing slurry 26 of carrier fluid and sand is pumped down the work string 24, through cross over 28 and out port 38. The fluid flowing out port 38 flows down the medial annulus and out packing ports 50 to form a sand pack in both the medial annulus and the outer annulus. If a sand bridge forms in the outer annulus, the slurry may flow down the medial annulus to the next packing port 50 and then into the outer annulus to form the desired sand pack below or past the sand bridge. In embodiments where slurry 26 is flowed through crossover port 40 into the outer annulus and a sand bridge forms, the slurry flowing in the outer annulus may flow through one or more of the packing ports 50 into the medial annulus to bypass the sand bridge.

[0033] As noted above, a sand bridge in the outer annulus is likely to form at the location of a very permeable portion of the open hole 20, for example a fracture. Prior art shrouds include a large number of ports over the entire shroud, since a large number is desirable for production purposes. The ports near the sand bridge allow a considerable amount of carrier fluid to flow into the formation. This reduces the amount of carrier fluid available to flow sand further down the

well to form the desired pack and increases the slurry density and viscosity requiring higher pressure or reducing flow rate. In the present invention, only a relatively small number of packing ports 50 are used during the packing operation, reducing the fluid loss in this situation.

[0034] After the desired sand pack has been achieved, it is normally desirable to place the well on production, i.e. allow produced fluids to flow from the well 10, through the screen 22 and up a production tubing with which the work string 24 and cross over 28 have been replaced. At that time it is desirable that the shroud 34 have a large number of ports so that the flow of produced fluids is not restricted. In the present invention, this production configuration is achieved by removal of the plugs blocking the production ports 48, by various means including those described below.

[0035] As shown in Fig. 1, there are relatively few packing ports 50. In some embodiments, the packing ports 50 may be round holes from about one-eighth inch to three-quarter inch in diameter, and preferably from about one-quarter inch to one-half inch in diameter. In some embodiments, the ports 50 may be spaced axially along the length of shroud 34 at intervals of from about two feet to about twelve feet and preferably from about three feet to about six feet. The packing ports 50 at each axial location may comprise groups of perforations evenly distributed about the circumference of the shroud 34. For example in various embodiments, three ports may be spaced 120 degrees apart, four ports may be spaced 90 degrees apart, six ports may be spaced 60 degrees apart, or twelve

ports may be spaced 30 degrees apart. The number of ports in each group depends on well and shroud diameters and other conditions.

[0036] In some embodiments, the production ports 48 may be round holes having diameters of from about one-eighth inch to about two inches and preferably from about three-eighths inch to about three-quarters inch. In some embodiments, the ports 48 may be evenly or randomly distributed over the shroud 34 to provide, in combination with the packing ports, an open area of from about five percent to forty percent of the shroud 34 total wall area and preferably from about ten percent to about twenty-five percent of the shroud 34 total wall area.

[0037] The material used to plug the production ports 48 during the packing operation is preferably a material which is sufficiently strong and durable to block flow out of the shroud 34 during packing, but which will degrade and disappear as a result of contact with borehole fluids. In one embodiment, the plug material may be formed of polylactic acid, which combines with water to degrade to lactic acid. The resulting acid may be beneficial in cleaning out the well in preparation for production. In oil wells, an oil soluble resin may be used for the removable plugging material. Both of these materials degrade at slow enough rates that they would retain sufficient strength during the packing operation, which may be performed in a short time. They should degrade completely within one to two weeks when in contact with borehole fluids. Since well completion activities normally performed after packing may take from one to several weeks, this

degradation time typically will not delay production. With these types of materials, the shroud 34 automatically changes from packing configuration to production configuration without any further action.

[0038] The production port blocking material may also be partially or entirely made of other chemicals used to treat oil wells. Such materials include phosphate scale inhibitors or encapsulated inhibitors. Solidified or encapsulated glycols may be used to provide hydrate suppression. Solidified or encapsulated materials of an acidic or caustic nature may aid in filter cake removal. Treatment materials may be mixed with or bound together with other materials, such as the polylactic acid mentioned above. When the blocking materials are removed after the packing process, the chemicals may be released to perform their normal well treatment function.

[0039] The production port blocking material may alternatively be a material that degrades as a result of an injected material such as an acid or base. The plug material may be for example a metal such as zinc, aluminum, magnesium or alloys of these metals which are acid soluble, for example in hydrochloric acid. A mixture of magnesium oxide and magnesium chloride may also form a suitable plugging material that is soluble in hydrochloric or sulfamic acid. If these materials are used to block the production ports 48, acid may be injected into the sand pack or circulated inside the screen 22 after the packing operation is completed to dissolve the production port plugs. Fluids circulated inside the screen 22 would be designed to easily permeate the sand pack between the

screen 22 and the production ports 48 to remove the plugs. The wash tube 32 may be useful in placing or circulating the acid as the tube is removed from the well.

[0040] The production port blocking materials may be molded or otherwise formed into plugs, see Figs. 2A through 2E, which may be placed in the production ports 48 to block flow during the packing operation. The plugs may be held in place by friction, e.g. a press fit, or may have threads, lips, flanges, or other means for mechanically engaging the ports 46. The plugs may include an outer metal sleeve.

[0041] For example, Fig. 2A illustrates a plug 47 having a metal sleeve 51 with an outer thread 49. Pressed or otherwise formed within the sleeve 51 is a quantity of one of the removable materials 53 described above. The inner surface of the ports 46 may be threaded to engage the threads 49 on the sleeve 51 of the plug 47. Upon removal of the blocking material 53, the threaded sleeve 51 may remain in place and the production ports would then be defined by the space within the sleeve.

[0042] Fig. 2B illustrates a plug 60 comprising removable material without an outer sleeve. The plug 60 may have a straight outside surface 62 and outer diameter sized to form a press or interference fit within the ports 46 as indicated on the right side of Fig. 2B. Alternatively, flanges or lips 64, as shown on the left side of Fig. 2B, may be provided to engage the ports 46. The lower flange 64 may be tapered to aid in inserting the plug 60 into a port 46.

[0043] Fig. 2C illustrates a plug 66 of removable material encased in a metallic sleeve 68. The sleeve 68 may have a straight outside surface 70 and outer diameter sized to form a press or interference fit within the ports 46 as indicated on the right side of Fig. 2C. Alternatively, flanges or lips 72, as shown on the left side of Fig. 2C, may be provided to engage the ports 46. The lower flange 72 may be tapered to aid in inserting the plug 60 into a port 46. If desired, slots 74 may be formed in the lower edge of sleeve 68 to enhance flexing of the lower flanges 72 during insertion of the plug 66 into a port 46.

[0044] Fig. 2D illustrates a plug 76 of removable material without an outer sleeve. The outer surface of plug 76 is threaded for engagement with a port 46. The plug 76 also includes a port 80 which will allow flow of slurry and/or fluids during the packing process, depending on the diameter of the port 80 as discussed below. The plugs shown in Figs. 2A-2C may likewise have a port if desired.

[0045] The production ports 48 may also be plugged with friable materials that may be broken up by pressure waves or other vibration sources. After the sand pack is formed a pressure impulse or vibration source may be lowered into the sand screen 22, or carried in on the washpipe 32 but not actuated until after packing, to break up such plugs and thereby open the production ports 48.

[0046] The production ports 48 may also be plugged with materials that melt or disintegrate when heated above a preselected temperature. One type of such material is known as a transitional metal and may be formed from various alloys

of bismuth. The melting temperature may be selected by adjusting the ratios of materials used to make the alloy. The temperature would be above the normal temperature in a well and thus may be selected for the particular well being gravel packed. After the gravel pack is formed, a heat source, e.g. electrical, hydro mechanical or chemical, may be activated in the well interval to remove the heat sensitive plugging material.

[0047] The production ports 48 may also be plugged with check valves or other forms of one-way valves. The valves would be positioned to allow flow from the outer annulus to the medial annulus, but to block flow in the opposite direction. By use of such valves, the well may be put on production immediately after packing if desired. The pressure differential driving produced fluids from the formation to the screen will automatically open the check valves and allow the desired flow of produced fluids. Under some operating conditions, such check valves may have an added benefit during the gravel packing operation. If slurry is flowed through the port 40 into the outer annulus, the check valves may open above a sand bridge to improve flow from the outer annulus to the medial annulus to improve the slurry flow and subsequent gravel pack adjacent the sand bridge. During the beta wave portion of a gravel pack operation, such check valves may open in the lower end of the shroud 34 to allow carrier fluid to flow through the medial annulus and screen 22 to reach the wash pipe 32.

[0048] Fig. 2E illustrates a plug 82 similar to the Fig. 2D embodiment, in which a check valve has be formed from the removable material as an integral part of

the plug 82. The plug 82 has a central port 84 extending from its top almost to the bottom 86 which would be positioned adjacent the inner surface of shroud 34. A 45 degree cut 87 has been made through the bottom 86 in a circular shape to form a flap 88 covering the bottom of the port. The cut 87 may be made, e.g. by a laser for a close fit. The cut does not extend in a full circle so that the flap 88 remains connected to the body of plug 82 on one point 90. The connection 90 may extend over one-eighth of the way around the flap 88. The connecting portion 90 acts as a hinge allowing the flap 88 to move downward in response to pressure from outside the shroud 34 and allowing fluid to flow into the shroud 34. However when pressure in the medial annulus is greater than the pressure in the outer annulus the pressure differential tends to close the flap 88 preventing fluid flow through the port 84.

[0049] As noted above, the packing ports 50 generally are smaller than the production ports 48. In one embodiment, all of the ports 46 may be initially formed with the larger diameter suitable for use as a production port. Two types of plugs 47 may then be produced. One type would be solid plugs that are inserted in the ports 46 which are designated as production ports. The second type of plugs would have an opening through the plug having a size selected to act as a packing port. The second type of plugs would be inserted into those ports 46 selected to act as packing ports. This embodiment has advantages in terms of production of the shrouds 34. Only one size port 46 needs to be drilled in the shroud 34 and there is no need to select the number or locations of

packing ports at the time the basic shroud 34 is made. Those selections can be made when the plugs 47 are installed into the ports 46.

[0050] In some cases it may be desirable for the shroud 34 to be completely sealed as it is lowered into position in a well, e.g. to reduce plugging of the screen 22 by drilling mud, etc. In that case, all of the ports 46 may be blocked with removable plugs. However, the plugs used to block production ports 48 may be made of a different removable material than is used to block the packing ports 50. After the shroud is placed in position in the well, the packing port plugs may be removed by a first treatment, which does not affect the plugs in the production ports. Then after the packing operation, a second treatment may be used to open the production ports.

[0051] In another embodiment, all or part of the plugs 47 may be made with a small opening, e.g. one-eighth inch or less. The opening size may be selected based on size of gravel used to form the gravel pack. The size would be small enough that the gravel would tend to bridge off in the ends of the small opening and restrict flow of gravel while allowing limited carrier fluid flow. The small openings in the plugs may aid in dewatering of the gravel pack in the outer annulus without generating undesirable leakage into high permeability zones. In one embodiment about twenty percent of the production port plugs 47 would have this feature.

[0052] Figs. 3A to 3D illustrate alternative embodiments of packing ports 50 in the shroud 34. The ports 50 each include a round hole as shown in Fig. 1. In

addition, pressure limiting tubes may be positioned within and through the ports 50. The tubes may have non-circular cross sections, e.g. oval or rectangular, which may reduce the radial space required for the tubes. Each tube may have an inner flow area equal to a tube with a circular inner diameter of between three-sixteenth inch and three-eighth inch and a length of from one-half inch to twelve inches. The space between the outer diameter of each tube and its respective packing port 50 is sealed so that all flow through the port 50 must pass through the tube.

[0053] In Fig. 3A are shown S shaped pressure limiting tubes 52, 54. This shape facilitates fitting the tubes through the ports 50, but allows the ends and majority of the tube length to be positioned against an inner and/or outer surface of the shroud 34. This shape is desirable for two reasons. It minimizes the radial space occupied by the tubes 52, 54. It also directs the flow of slurry so that it does not impinge directly on the screen 22 or the borehole 10, depending on which way the slurry flows. The tubes 52 and 54 may be identical, but as illustrated may be positioned to direct flow either up hole or down hole. Alternatively, the round port 50 may be replaced by a slot and the tubes 52, 54 may be substantially straight and positioned in the slot with one end exposed in the inside and the other on the outside of the shroud 34.

[0054] Fig. 3B illustrates an L shaped pressure limiting tube 92. The short leg 94 may have a length about equal to the thickness of shroud 34, so that it does not extend beyond the outer surface of the shroud, to avoid damage when the

shroud is installed in the well. The long leg 96 may be directed either up hole or down hole as desired, and lies close to the inner surface of the shroud 34.

[0055] Fig. 3C illustrates a C shaped pressure limited tube 98. Tube 98 has longer legs 100 extending along both the inner and outer surfaces of shroud 34. The legs 100 may directed either up hole or down hole as desired. The short connect leg 102 has a length sufficient to fit through the port 50.

[0056] Fig. 3D illustrates a modified L shaped pressure limiting tube 104. The short leg 106 of tube 104 is bent at less than ninety degrees relative to the long leg 108, which is positioned against the inner wall of the shroud 34. The outer annulus end 110 of the tube 104 therefore does not flow slurry directly at the wall of the well. The tube 104 may be positioned with the long leg 108 directed up hole or down hole as desired.

[0057] The pressure limiting tubes 52, 54, 92, 98, 104 may help reduce carrier fluid loss when a high permeability zone is encountered and produces a sand bridge near or at the location of one or more of the packing ports 50. The bridge will grow towards the port 50 as slurry flows through the port toward the leak off zone. At some point, the bridge will grow into the closest pressure limiting tube. The tube will then pack with the sand and only the carrier fluid will continue to flow through the tube. However, once the tube is packed with sand, its flow resistance increases greatly and the flow of carrier fluid will be much lower than the flow of slurry at the same pressure drop. The amount of flow restriction is dependent on the length and inner diameter of the pressure limiting tube. While

the tubes 52, 54, 92, 98, 104 have been referred to as pressure limiting tubes, it can be seen that they also limit fluid flow and therefore fluid loss to a high permeability zone such as a fracture.

[0058] Fig. 4 illustrates an alternative embodiment for blocking flow through production ports 48 of the shroud 34. In this embodiment, a removable sleeve 56 is carried on the inner surface of the shroud 34. The sleeve 56 may be made of any of the removable blocking or plugging materials described above. The sleeve 56 is a thin hollow cylinder having ports arranged in alignment with the packing ports 50. The sleeve 56 otherwise has a solid wall which covers the production ports 48 and blocks flow, especially from the interior of the shroud 34 to its exterior. As noted above, flow in the opposite direction is acceptable, and in some cases an advantage in embodiments of the invention. The sleeve 56 may be a separate part bonded, e.g. glued, to the inner surface of the shroud 34 or it may be molded in place on the inner surface of shroud 34 or otherwise mechanically attached. This embodiment would be used in the same manner as described above. That is, the packing ports supply a desirable amount of permeability during the packing operation. It may be desirable for pressure-limiting tubes 52, 54 to be inserted in each of the packing ports 50 for the reasons discussed above. After a packing operation is performed, the sleeve 56 may be removed or dissolved, by contact with ambient fluids or by injection of acid, heating etc. to open the production ports 48.

[0059] The geometry of the present invention provides benefits of both prior art shroud systems and prior art shunt tube or bypass conduit systems. The shunt tube system provides a dedicated slurry path that distributes the slurry along the length of the packing interval to bypass sand bridges. However, the tubes have limited cross sectional area and often require higher pressures to flow the slurry into the interval. It is also difficult to connect the shunt tubes between adjacent screen assemblies when multiple assemblies are installed in a well, which is a typical arrangement. The shunt tubes make it difficult to install control and sensing lines in the string. The simple geometry of a shroud type system avoids these problems, but does not provide the same slurry distribution benefits of the shunt tube system.

[0060] The present invention has the simple geometry of a shroud type system. It provides a relatively large flow path for slurry so that pumping pressure may be minimized and provides room for easily running control or sensing lines in the medial annulus. At the same time, it provides packing ports that may be sized and positioned in essentially the same way as ports in shunt tube systems are sized and positioned. When the blocking or plugging material is removed from the production ports 48, the shroud 34 has the full production flow capacity of prior art shrouds.

[0061] It may be desirable for the screen 22 to be decentralized or eccentrically positioned relative to the shroud 34. Such positioning generally reduces the friction pressure in the medial annulus and would therefore reduce

the pressure required to flow slurry through the medial annulus. It may also provide more space for control or sensing lines.

[0062] In Fig. 1, the top of the shroud 34 is shown as being attached to the cross over tool 28 so that flow through port 38 is forced into the medial annulus. In some embodiments, the top of the shroud 34 is open and a single port 38 or 40, or both ports 38 and 40, may flow slurry into the annulus above shroud 34. In that case, flow may be directed primarily into the medial annulus, if desired, by various means. Generally this may be accomplished by providing a close fit of the upper end of the shroud 34 to the casing 16. The shroud itself may be sized, at least at its upper end, to leave little outer annulus space between the shroud 34 and the casing 16. The cup seals 36 shown in Fig. 1 are another way of directing flow to the medial annulus, by sealing off the pathway to the outer annulus.

[0063] Directing most of the slurry flow initially to the medial annulus is generally preferred for various reasons. Once a sand bridge forms in the outer annulus, the slurry flow in the outer annulus will be blocked and it must enter the medial annulus to bypass the sand bridge. By directing the initial flow into the medial annulus, the velocity of flow is best maintained, thus keeping the sand in suspension, reducing flow pressure, and more efficiently delivering the slurry to the end of the interval. If slurry is pumped only into the medial annulus, the shroud of the present invention may isolate the well wall from the slurry pumping pressure, especially if the pressure limiting tubes 52, 54 are used, and prevent

undesirable fracturing or other damage to the formation. However, for ease of adaptability to conventional service tools, in some circumstances it may be more desirable to direct or pump slurry primarily outside the shroud initially or to both the medial annulus and the outer annulus.

[0064] In inclined or horizontal wells, the formation of a sand pack often occurs in a process involving an alpha wave and a beta wave. A horizontal well has a top "side" and a bottom "side". As slurry is first pumped into the interval to form a sand pack, the sand begins to drop out of suspension and form a sand pack on the bottom side of the well progressing from the upper, or heel, end to the lower, or toe, end of the interval. Once the sand pack has been formed in the lower side all the way to the lower end, it begins to build up a pack in the upper side progressively from the lower end back to the upper end. This upper side part of the process is called the beta wave portion. This process is a generally desirable way of forming a sand pack in a horizontal or slanted well interval.

[0065] In using the present invention, it is desirable to viscosify the carrier fluid slightly, but not enough to prevent formation of alpha and beta waves. The gel loading used to viscosify the fluid and/or the sand density may be reduced at or just before the onset of the beta wave to reduce friction pressures and to enhance tighter packing.

[0066] Pump rate may be relatively high because of the pressure and leak off containing ability and large flow area of the shroud of the present invention. For example, pump rates of five to ten barrels per minute may be used in 8.5 inch

open hole, with gravel/proppant concentrations of one to six pounds added per gallon of carrier fluid. The pump rate may be reduced at or just before onset of the beta wave to reduce friction pressure and to enhance tighter packing. The alpha wave may reestablish temporarily at a higher level corresponding to the lower rate before onset of the beta wave.

[0067] In order to tolerate transient conditions of velocity changes and pressure surges in the medial annulus which may result from the process of losing slurry through the packing ports 50 to the outer annulus until the outer annulus is packed, then transitioning to full flow in the medial annulus, it may be desirable to use a larger wash pipe 32 than is typically used in the prior art. For example, it may be desirable to use a wash pipe 32 having an outer diameter of about 0.9 of the inner diameter of the screen 22. This would significantly restrict the flow of carrier fluid in the inner annulus between the wash pipe 32 and the screen 22. Such a reduced inner annulus may cause undesirably high friction pressures during the beta wave. Pressure activated valves may be installed in the wash pipe 32 set to open when the beta wave passes their location in the well, thereby providing a shorter flow path for the returning carrier fluid and lowering the maximum pressure required.

[0068] One typical embodiment of the invention is designed for use in an 8.5 inch open hole below a nine and five-eighth inch casing. The shroud would have an outer diameter of seven and five-eighth inch, with flush joint threads. Each packing port 50 would have a pressure limiting tube 52, 54 with an inner diameter

of three-sixteenth inch and a length of three inches. The packing ports would be spaced along the shroud at intervals of about four feet and there would be four ports radially spaced about the shroud at each location. Each production port 48 would be about one-half inch in diameter with an internal thread. Each production port 48 would be temporarily plugged with metal-sleeved plugs with polylactic acid cores, which hydrolyze to lactic acid in ten days, leaving three-eighth inch diameter flow ports. Sufficient production ports would be formed in the shroud to provide an open area equal to about thirty percent of the total shroud surface area. The screen 22 would have a base pipe having an inner diameter of about five inches. The wash pipe 32 would have an outer diameter of about four and one-half inches.